DEVELOPMENT AND FABRICATION OF A
150-800 MHz 1Kw CW POWER SOURCE
(EIMAC MODEL NO. ETS4800)

THIRD QUARTERLY PROGRESS REPORT
FOR PERIOD
JANUARY 1, 1967 TO MAY 19, 1967

FOR

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

P.O. NO. AU-~~37065~~ 370935

PREPARED BY

EIMAC, DIVISION OF VARIAN ASSOCIATES
SAN CARLOS, CALIFORNIA

THIS WORK WAS PERFORMED FOR THE JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY, SPONSORED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION UNDER CONTRACT NAS 7-100.

WRITTEN BY:

Glen L. Hatley
ETS4800 Project Engineer
Aerospace Products Division

APPROVED BY:

Lester L. Libby
Chief Engineer
Aerospace Products Division

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D.C.

Attention: AFSS-A

TABLE OF CONTENTS

I. OBJECTIVE

The objective of this contract is to develop and fabricate a self-contained laboratory power signal source which provides a minimum output of 1Kw CW over the continuously tunable frequency range of 150 to 800 MHz. Although it is not a contractual requirement, it is an additional goal of this development to provide some useful power output in the range of 800 to 1000 MHz.

Size of the unit is critical, since it will be installed in a limited space; therefore, the power source shall be contained in a maximum of 3 standard 19" racks, with the maximum depth not exceeding 28", and the maximum height not exceeding 72" including casters.

The unit shall be designed to operate under varying conditions of power, frequency, and high load mismatch as encountered in high power breakdown testing of components under laboratory conditions.

II. GENERAL DESCRIPTION OF SYSTEM

As an aid to understanding the various portions of this system and their relation to each other, refer to the block diagram (EIMAC Drawing Number C-185748) in the Appendix of this report.

A. RF Generation

The rf power output of the system is generated by a low power cavity oscillator, and the signal from the oscillator is amplified by two stages of cavity amplifiers to the 1Kw CW level. The oscillator is an EIMAC Model EM-4555, which is tunable over the frequency range of 150-1050 MHz and provides a signal in the order of 10 to 50 watts to drive the intermediate amplifier. A complete description and photograph of this oscillator can be found in the four-page data sheet in the Appendix of this report. The intermediate amplifier is a standard EIMAC Model EM-4547. This unit is tunable over the 150-1000 MHz frequency range, and with 10 watts drive, it will provide a minimum output power of 100 watts. A four-page data sheet on the EM-4547 is also included in the Appendix of this report.

The final amplifier, which is driven by the 100 watt output of the EM-4547, represents the major development effort of this program, since this unit was completely designed for this system. Basically, the approach taken was to borrow the design principles of the EM-4547 and modify them for the higher power level involved. The choice of tube for the 1Kw CW output level was a difficult one, due to the fact that practically all of the tubes available at this power level and frequency range are tetrodes. Since the use of a tetrode in a six-to-one tuning range cavity amplifier posed some particularly difficult design problems, a triode was felt to be the only reasonable choice for this amplifier. After considerable searching for a 1Kw CW, 1 GHz triode, the only satisfactory production tube found was the Nippon Electric LD-551 metal-ceramic planar triode. Therefore, the LD-551 triode was chosen for this application.

B. Power Supplies

All of the necessary dc power supplies to power the three rf stages described above, and all of the auxiliary functions of the system, such as the modulator, square wave generator, relay resets, etc. are provided in ths system. All of these supplies are fully regulated. The other items requiring ac power, e.g., the cooling pump motor, the motor for the Variac, which controls the B+ on the amplifiers, relays, lights, etc., are supplied by one phase (120 volts) of the 208 volt, three-phase, 60 Hz, five-wire primary input.

Basically, the power supplies are divided into separate groups, namely the oscillator B+ supply, the amplifier B+ supplies, and the filament and bias supplies. The oscillator supply is made up of three commercial dc supplies in series to provide the 1Kv at 125 mA maximum required for the oscillator. This voltage is adjustable to reduce the oscillator power output at the lower frequencies. The amplifier B+ supply was built at EIMAC and consists of 0-1Kv at 250 mA for the EM-4547, and 0-3Kv at 1 Amp for the final amplifier. Both of these voltages are adjustable by means of a motor-driven Variac to control the power output of the system. The filament and bias supplies were also built at EIMAC and consist of regulated 60 Hz filament supplies and other regulated dc voltages for the other requirements of the system.

C. Modulation

Modulation is accomplished by cathode modulation of the driver amplifier. Since cathode modulation is more reliable and requires lower voltage levels, it was chosen as the modulation scheme. The modulator is all solid-state and can best be described as a switch that switches from one fixed bias level to an adjustable discrete bias level. This allows continuous adjustment from the no modulation case to full 100%.

A built-in square-wave generator capable of adjustable operation over a frequency range of 400-2500 Hz is also provided. Alternately, this generator is switchable to a precision 1000 Hz ± 0.05% square-wave frequency. An external modulation input is also provided.

D. Monitoring and Control Circuitry

In general, all critical voltages and currents of each stage are monitored simultaneously during tuning and operation of the system. In addition, forward and reverse rf power of the oscillator and intermediate amplifier outputs can be read directly from rf power meters. The final amplifier output has two separate direct-reading power meters for forward and reverse power, and the reverse power meter includes a settable relay for automatically turning off the rf power if the safe maximum reverse rf power level is exceeded.

Other monitoring functions include a 20db coupler in the line between the oscillator and the intermediate amplifier for external monitoring of frequency, a 40db coupler in the output line for frequency monitoring, a modulation level meter, an operating time meter on the rf tube filaments, and a number of lights indicating various functions in the system such as phase failure, interlocks, water flow, power on, etc.

Each rf section has its own control panel with all tuning adjustments and controls necessary for the function of that unit. Dummy loads for the output of the oscillator and intermediate amplifier are self-contained in the system for use during tune-up of that stage. These loads are switched in from the front panel. Variation of the final rf output power can be accomplished from either the front panel or by remote control. Extensive interlock circuitry is provided for all critical functions, such as cooling water flow, cabinet cooling, time delay, door interlocks, grid or high voltage overloads, external interlocks, etc. For a complete summary of all controls and monitoring circuitry, the block diagram, and panel layout, in the Appendix should be consulted.

E. Cooling

Cooling is provided by two separate systems. Air cooling of the various electronic components and the system in general is accomplished by a filtered air inlet with a motor-driven fan at the bottom back of the unit. This air is exhausted out through the top. Cooling of the higher powered elements; e.g., the two amplifier tubes, is provided by an internal closed cycle water cooling system. The exhaust air and the heat exchanger for the water cooling system is located at the bottom right hand side of the cabinet.

F. Packaging

The complete system is packaged in a three-bay rack which measures approximately 72" in height, 74" in width, and 24" in depth. Six 4" heavy duty casters are included, one on each of the four corners, and two in the middle. Two foot-pedal lockable pads are provided to prevent movement of the cabinet. The bottom of the cabinet is strengthened and suitable cutouts provided so that a fork-lift can be used to pick up the unit.

Location of all the separate panels and the associated controls, meters, etc. is shown in detail on the panel layout in the Appendix (EIMAC Drawing Number D-185746).

III. PROGRESS DURING THE REPORTING PERIOD

This report is intended to cover the period from January 1, 1967 to May 19, 1967. It is understood the period is somewhat longer than the specified three months, but it is purposely being extended to cover the period of final testing. In this way this report can serve as both the third and final Quarterly Report.

During this reporting period the entire system has been assembled and tested. The milestone chart and program schedule reflects the completion times of the various sub-assemblies and testing programs.

The first seven weeks of this reporting period were required to resolve the difficulties that arose in the 1Kv and 3Kv high voltage power supply, resulting in some slippage of the over-all program. The assembly and some preliminary testing of the power supply were completed during the second week of January. Further tests disclosed an oscillation problem; and although this was readily eliminated in the 1Kv supply section, it remained a problem in the 3Kv supply section. Another problem was posed by the failure in the regulator tube screen grid supply circuit of both the 1Kv and 3Kv supplies, and this was resolved by ungrading their power rating. In early February the oscillation problem encountered in the 3Kv supply was solved by lowering the impedance of the screen circuit on the 4CX1000A regulator. After preliminary testing, the power supply unit was considered finished on February 22nd. Tests indicate the ripple is 50 millivolts on the 1Kv supply and 75 millivolts on the 3Kv supply. During the early fabrication of the high voltage power supply, it was decided to replace the originally proposed water-cooled regulator tubes with air-cooled tubes. The tubes now employed are the 4CX250B in the 1Kv supply, and the 4CX1000A in the 3Kv supply. This decision was made earlier in the program after changing the modulation method to a low level scheme, and obviously air-cooling these tubes significantly reduced the complexity of the internal water cooling system.

January also saw the completion of the oscillator control panel, the driver amplifier control panel and the square wave generator. Included in the driver amplifier assembly is the dummy load and coaxial relay, as well as a regulated filament supply. Mounted on the square wave generator panel is its power supply which is also utilized for the modulation meter circuit and the reset voltage for the latching relays.

The final amplifier control panel was finished in February and, with one exception, worked as expected. The trouble which developed was due to meter relay polarity of the reverse power wattmeter. This was discussed in the eigth monthly letter progress report and was resolved without difficulty by substituting a diode of opposite polarity in the Sierra Power Monitor. Preliminary testing of the unit was started at the end of February and no significant difficulties were indicated at that time. The modulator had not been completed as of that time, and tests using a breadboard circuit to determine the requirements enabled the simplification of the unit by the use of only one modulator. It was found that by modulating the driver only and with a fixed bias of 40 volts on the final amplifier, the signal feed-through during the "Off" time of the square wave modulation was at least 34db below the "On" level.

IV. TECHNICAL PROBLEMS ENCOUNTERED AND RESOLUTION

The significant problems which did arise during the final phase of this development are centered around the Nippon Electric Co. LD-551 Planar Triode.

The first problem became evident during tuning of the final amplifier. When tuning up for optimum output at frequencies above 500 MHz there is at times an instability of power output which is evidenced as an inter-dependence of the tuning of the cathode line and the plate line. This effect is apparent only at high power and can be minimized by setting the output coupler to a position where the final plate cavity is slightly over-coupled.

The second problem is one which has not been fully resolved as of this writing and involves the failure of two tubes which we intended to install and deliver with the test set.

The decision to use the LD-551 triode in the final amplifier stage was made in the early part of 1966. The test data supplied with Serial #M-32 tube by Nippon Electric showed a power output of 1008 watts in their test cavity as an oscillator at 900 MHz. The published typical operating characteristics furnished for this tube type indicated a useful power output of 950 watts at 800 MHz in Class B amplifier service. Using this information as a basis for making the decision to use this tube type, it was considered safe to expect one kilowatt of useful power as a Class C amplifier throughout the frequency range of 150 to 800 MHz.

In November, 1966 tests were made using the first purchased tube #M-32. Results of these tests indicated that by operating the tube at its maximum rated plate voltage (3000V) and current (700 mA), 1000 watts of useful power output could be achieved. Under these conditions the plate dissipation was 1100 watts, hence well under the 2100 watt dissipation rating. Since the cavity was not plated in this initial test, it was expected that better performance with a greater margin of safety would be achieved when the cavity was ultimately plated.

The construction continued using the original tube #M-32 for all testing. There were several occasions when the tube was momentarily operated above its rated limits. This is not unusual during the development phase of an amplifier of this type, and no evidence of damage to the tube was encountered.

In March, when the test set was essentially finished, a new tube, serial #P-59, was installed for the start of the final test program. The tube failed after only ten minutes of operation, the cause of failure being a circumferential crack in the ceramic between grid and plate. The operation during the short time prior to failure indicated the tube had somewhat lower output than tube #M-32, possibly the consequence of a gassy condition associated with the ceramic crack.

The failure raised the question of how it would be possible to insure getting the required output of one kilowatt if tubes from Nippon Electric do not "measure up" to the performance characteristics exhibited by #M-32. A study of all test data supplied from Nippon Electric indicated we could not expect more than approximately 750 watts (as a 900 MHz amplifier) out of a tube which would still be within their specifications. In fact a tube could be about 20% below their published"typical" characteristics and still be within their minimum specifications for shipment.

A new tube was ordered, and expedited delivery was promised in three weeks. In order to accelerate the delivery of the completed Test Set, we decided to proceed with the final acceptance testing using the original tube #M-32. However, since Nippon Electric did say the tubes in stock tested with an output of no more than 780 watts in their oscillator test (equivalent to about 830 watts as a 900 MHz amplifier) and the original tube #M-32 produced 1008 watts in the same test, we did believe that we could offer the best for all concerned by testing and delivering the unit with the best tube available. The fact that subsequent tubes may not come up to the performance of the original is a matter of concern, but is understandable in the light of the state-of-the-art nature of this equipment.

On May 10th the second new tub e, #PD5, was ready for installation and testing in the amplifier. During the initial tune-up of the amplifier with this new tube, it arced internally and failed.

There is now no doubt that the data published by Nippon Electric as "typical" for the LD-551 is not appropriate for the tubes they are supplying at this time. Perhaps they will in the future be able to supply tubes as good as their published "typical" data reflects; or they may even be able to advance the state-of-the-art by producing an even better planar triode.

In order to resolve this problem EIMAC has contacted the technical representative for Nippon Electric in this country. We have also ordered two new tubes which we intend to test in the unit in order to assure the best performance possible.

V. PROGRAM FOR NEXT PERIOD

The Test Set is finished and ready for shipment. Work is progressing on the instruction manual and it is anticipated it will be ready for delivery with the equipment.

A meeting between the Technical Engineer of Nippon Electric Co. and the Engineering Head of our planar triode section is scheduled for the first week in June. All aspects of the tube problem will be discussed in an attempt to resolve them.

VI. APPENDIX

Included in the Appendix to this report are the following items:

A. Drawings

1. D-185746 Revision 1 - Proposed Panel Layout

2. C-185748 - Block Diagram

B. Milestone Chart & Program Schedule

C. EIMAC Product Data Sheets

1. EM-4555, Broad Tuning Oscillator, 150-1050 MHz

2. EM-4547, Cavity Amplifier, 150-1000 MHz, 100 Watts CW

D. Photograph

1. Front View #13827-2